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5. Pushing a grocery cart with a force of 95 N, applied at an angle of 35° down from the horizontal, makes the cart travel at a constant speed of 1.2 m/s. What is the frictional force acting on the cart?

6. A man walking with the aid of a cane approaches a skateboard (mass 3.5 kg) lying on the sidewalk. Pushing with an angle of 60° down from the horizontal with his cane, he applies a force of 115 N, which is enough to roll the skateboard out of his way.
   (a) Calculate the horizontal force acting on the skateboard.
   (b) Calculate the initial acceleration of the skateboard.

7. A mountain bike with mass 13.5 kg, with a rider having mass 63.5 kg, is travelling at 32 km/h when the rider applies the brakes, locking the wheels. How far does the bike travel before coming to a stop if the coefficient of friction between the rubber tires and the asphalt road is 0.60?

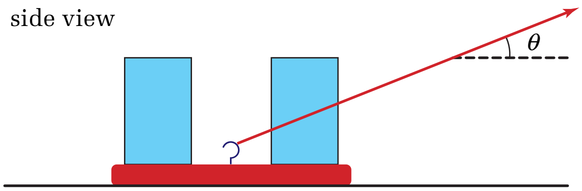
QUICK LAB

## Best Angle for Pulling a Block

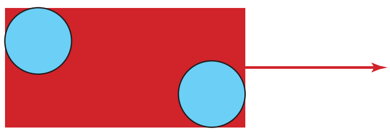
**TARGET SKILLS**
- **Predicting**
- **Performing and recording**
- **Analyzing and interpreting**

Set two 500 g masses on a block of wood. Attach a rope and drag the block along a table. If the rope makes a steeper angle with the surface, friction will be reduced (why?) and the block will slide more easily. Predict the angle at which the block will move with least effort. Attach a force sensor to the rope and measure the force needed to drag the block at a constant speed at a variety of different angles. Graph your results to test your prediction.

side view




top view



### Analyze and Conclude

1. Identify from your graph the "best" angle at which to move the block.
2. How close did your prediction come to the experimental value?
3. Identify any uncontrolled variables in the experiment that could be responsible for some error in your results.
4. In theory, the "best" angle is related to the coefficient of static friction between the surface and the block: $\tan \theta_{best} = \mu_s$. Use your results to calculate the coefficient of static friction between the block and the table.
5. What effect does the horizontal component of the force have on the block? What effect does the vertical component have on the block?
6. Are the results of this experiment relevant to competitors in a tractor pull, such as the one described in the text and photograph caption at the beginning of this section? Explain your answer in detail.

## Applying Newton's Third Law

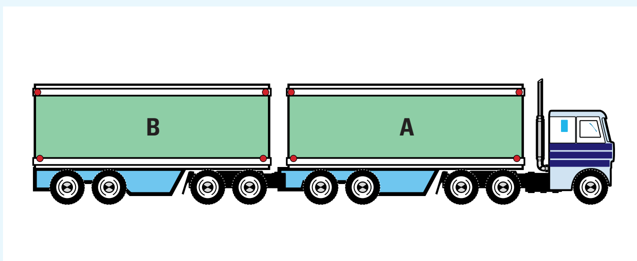
Examine the photograph of the tractor-trailer in Figure 1.7 and think about all of the forces exerted on each of the three sections of the vehicle. Automotive engineers must know how much force each trailer hitch needs to withstand. Is the hitch holding the second trailer subjected to as great a force as the hitch that attaches the first trailer to the truck?

**Figure 1.7** This truck and its two trailers move as one unit. The velocity and acceleration of each of the three sections are the same. However, each section is experiencing a different net force.

To analyze the individual forces acting on each part of a train of objects, you need to apply Newton's third law to determine the force that each section exerts on the adjacent section. Study the following sample problem to learn how to determine all of the forces on the truck and on each trailer. These techniques will apply to any type of train problem in which the first of several sections of a moving set of objects is pulling all of the sections behind it.

**SAMPLE PROBLEM**

### Forces on Connected Objects




**A tractor-trailer pulling two trailers starts from rest and accelerates to a speed of 16.2 km/h in 15 s on a straight, level section of highway. The mass of the truck itself (T) is 5450 kg, the mass of the first trailer (A) is 31 500 kg, and the mass of the second trailer (B) is 19 600 kg. What magnitude of force must the truck generate in order to accelerate the entire vehicle? What magnitude of force must each of the trailer hitches withstand while the vehicle is accelerating? (Assume that frictional forces are negligible in comparison with the forces needed to accelerate the large masses.)**

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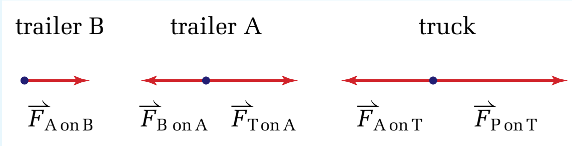
## Conceptualize the Problem

- The truck engine generates energy to turn the wheels. When the wheels turn, they exert a *frictional force on the pavement*. According to Newton's third law, the *pavement* exerts a reaction *force* that is equal in magnitude and opposite in direction to the force exerted by the tires. The force of the pavement on the truck tires, $\vec{F}_{\text{P on T}}$, *accelerates* the entire system.
- The truck exerts a *force* on trailer A. According to Newton's third law, the trailer exerts a *force of equal magnitude* on the truck.
- Trailer A exerts a *force* on trailer B, and trailer B therefore must exert a force of equal magnitude on trailer A.
- Summarize all of the *forces* by drawing *free-body diagrams* of each section of the vehicle.




- The *kinematic equations* allow you to calculate the *acceleration* of the system.
- Since each section of the system has the *same acceleration*, this value, along with the masses and *Newton's second law*, lead to all of the *forces*.
- Since the motion is in a straight line and the question asks for only the magnitudes of the forces, vector notations are not needed.

### Identify the Goal

The force, $F_{\text{P on T}}$, that the pavement exerts on the truck tires; the force, $F_{\text{T on A}}$, that the truck exerts on trailer A; the force, $F_{\text{A on B}}$, that trailer A exerts on trailer B

## Identify the Variables

**Known**

$v_f = 16.2\ \frac{\text{km}}{\text{h}}$

$\Delta t = 15\text{ s}$

$m_T = 5450\text{ kg}$

$m_A = 31\ 500\text{ kg}$

$m_B = 19\ 600\text{ kg}$

**Implied**

$v_i = 0\ \frac{\text{km}}{\text{h}}$

**Unknown**

$a$, $F_{\text{T on A}}$, $F_{\text{A on T}}$, $m_{\text{total}}$, $F_{\text{P on T}}$, $F_{\text{A on B}}$, $F_{\text{B on A}}$

## Develop a Strategy

Use the kinematic equation that relates the initial velocity, final velocity, time interval, and acceleration to find the acceleration.

$$a = \frac{v_2 - v_1}{\Delta t}$$

$$a = \frac{\left(16.2\ \frac{\text{km}}{\text{h}} - 0\ \frac{\text{km}}{\text{h}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right)\left(\frac{1000\text{ m}}{1\text{ km}}\right)}{15\text{ s}}$$

$$a = 0.30\ \frac{\text{m}}{\text{s}^2}$$

Find the total mass of the truck plus trailers.

$$m_{\text{total}} = m_T + m_A + m_B$$

$$m_{\text{total}} = 5450\text{ kg} + 31\ 500\text{ kg} + 19\ 600\text{ kg}$$

$$m_{\text{total}} = 56\ 550\text{ kg}$$

Use Newton's second law to find the force required to accelerate the total mass. This will be the force that the pavement must exert on the truck tires.

$$\vec{F} = m\vec{a}$$

$$F_{\text{P on T}} = (56\ 550\text{ kg})\left(0.30\ \frac{\text{m}}{\text{s}^2}\right)$$

$$F_{\text{P on T}} = 16\ 965\ \frac{\text{kg}\cdot\text{m}}{\text{s}^2}$$

$$F_{\text{P on T}} \cong 1.7 \times 10^4\text{ N}$$

The pavement exerts $1.7 \times 10^4$ N on the truck tires.

Use Newton's second law to find the force necessary to accelerate trailer B at 0.30 m/s². This is the force that the second trailer hitch must withstand.

$$F_{\text{A on B}} = m_{\text{B}}a$$
$$F_{\text{A on B}} = (19\ 600\ \text{kg})\left(0.30\ \frac{\text{m}}{\text{s}^2}\right)$$
$$F_{\text{A on B}} = 5.88 \times 10^3\ \frac{\text{kg} \cdot \text{m}}{\text{s}^2}$$
$$F_{\text{A on B}} \cong 5.9 \times 10^3\ \text{N}$$

The force that the second hitch must withstand is $5.9 \times 10^3$ N.

Use Newton's second law to find the total force necessary to accelerate trailer A at 0.30 m/s².

$$F_{\text{total on A}} = m_{\text{A}}a$$
$$F_{\text{total on A}} = (31\ 500\ \text{kg})\left(0.30\ \frac{\text{m}}{\text{s}^2}\right)$$
$$F_{\text{total on A}} = 9.45 \times 10^3\ \frac{\text{kg} \cdot \text{m}}{\text{s}^2}$$
$$F_{\text{total on A}} \cong 9.5 \times 10^3\ \text{N}$$

Use the free-body diagram to help write the expression for total (horizontal) force on trailer A.

$$F_{\text{total}} = F_{\text{T on A}} + F_{\text{B on A}}$$

The force that the first hitch must withstand is the force that the truck exerts on trailer A. Solve the force equation above for $F_{\text{T on A}}$ and calculate the value. According to Newton's third law, $F_{\text{B on A}} = -F_{\text{A on B}}$.

$$F_{\text{T on A}} = F_{\text{total on A}} - F_{\text{B on A}}$$
$$F_{\text{T on A}} = 9.45 \times 10^3\ \text{N} - (-5.88 \times 10^3\ \text{N})$$
$$F_{\text{T on A}} = 1.533 \times 10^4\ \text{N}$$
$$F_{\text{T on A}} \cong 1.5 \times 10^4\ \text{N}$$

The force that the first hitch must withstand is $1.5 \times 10^4$ N.

### Validate the Solution

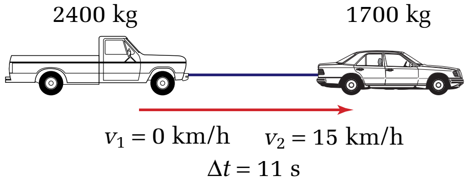
You would expect that $F_{\text{P on T}} > F_{\text{T on A}} > F_{\text{A on B}}$. The calculated forces agree with this relationship. You would also expect that the force exerted by the tractor on trailer A would be the force necessary to accelerate the sum of the masses of trailers A and B at 0.30 m/s².

$$F_{\text{T on A}} = (31\ 500\ \text{kg} + 19\ 600\ \text{kg})\left(0.30\ \frac{\text{m}}{\text{s}^2}\right) = 15\ 330\ \text{N} \cong 1.5 \times 10^4\ \text{N}$$

This value agrees with the value above.

## PRACTICE PROBLEMS

**8.** A 1700 kg car is towing a larger vehicle with mass 2400 kg. The two vehicles accelerate uniformly from a stoplight, reaching a speed of 15 km/h in 11 s. Find the force needed to accelerate the connected vehicles, as well as the minimum strength of the rope between them.




**9.** An ice skater pulls three small children, one behind the other, with masses 25 kg, 31 kg, and 35 kg. Assume that the ice is smooth enough to be considered frictionless.

**(a)** Find the total force applied to the "train" of children if they reach a speed of 3.5 m/s in 15 s.

**(b)** If the skater is holding onto the 25 kg child, find the tension in the arms of the next child in line.

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**10.** A solo Arctic adventurer pulls a string of two toboggans of supplies across level, snowy ground. The toboggans have masses of 95 kg and 55 kg. Applying a force of 165 N causes the toboggans to accelerate at 0.61 m/s$^2$.

**(a)** Calculate the frictional force acting on the toboggans.

**(b)** Find the tension in the rope attached to the second (55 kg) toboggan.

## 1.2 Section Review

**1.** K/U How is direction represented when analyzing linear motion?

**2.** K/U When you pull on a rope, the rope pulls back on you. Describe how the rope creates this reaction force.

**3.** K/U Explain how to calculate

**(a)** the horizontal component ($F_x$) of a force $F$

**(b)** the vertical component ($F_y$) of a force $F$

**(c)** the coefficient of friction ($\mu$) between two surfaces

**(d)** the gravitational force ($F_g$) acting on an object

**4.** K/U Define (a) a *normal* force and (b) the weight of an object.

**5.** K/U An object is being propelled horizontally by a force $F$. If the force doubles, use Newton's second law and kinematic equations to determine the change in

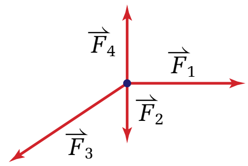
**(a)** the acceleration of the object

**(b)** the velocity of the object after 10 s

**6.** K/U A 0.30 kg lab cart is observed to accelerate twice as fast as a 0.60 kg cart. Does that mean that the net force on the more massive cart is twice as large as the force on the smaller cart? Explain.

**7.** K/U A force $F$ produces an acceleration $a$ when applied to a certain body. If the mass of the body is doubled and the force is increased fivefold, what will be the effect on the acceleration of the body?

**8.** K/U An object is being acted on by forces pictured in the diagram.




**(a)** Could the object be accelerating horizontally? Explain.

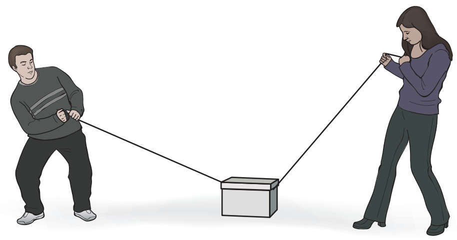
**(b)** Could the object be moving horizontally? Explain.

**9.** C Three identical blocks, fastened together by a string, are pulled across a frictionless surface by a constant force, $F$.


**(a)** Compare the tension in string A to the magnitude of the applied force, $F$.

**(b)** Draw a free-body diagram of the forces acting on block 2.

**10.** K/U A tall person and a short person pull on a load at different angles but with equal force, as shown.



**(a)** Which person applies the greater *horizontal* force to the load? What effect does this have on the motion of the load?

**(b)** Which person applies the greater *vertical* force to the load? What effect does this have on frictional forces? On the motion of the load?